Renewable and Sustainable Energy Reviews 30 (2014) 912–922

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Trends and challenges of sustainable energy and water research in North Africa: Sahara solar breeder concerns at the intersection of energy/water

A. Boudghene Stambouli [a,b,c,*], Z. Khiat [a], S. Flazi [a], H. Tanemoto [b,d], M. Nakajima [c], H. Isoda [c], F. Yokoyama [d], S. Hannachi [b,d], K. Kurokawa [b,e], M. Shimizu [b,f], H. Koinuma [b,c,d,g], N. Yassaa [h]

[a] *University of Science and Technology of Oran, USTO-MB, Algeria, BP 1505, EL M'Naouer, Oran 31000, Algeria*
[b] *Sahara Soar Breeder Foundation (SSBF), Japan*
[c] *ARENA (Alliance for Research for North Africa), Tsukuba University, Japan*
[d] *Nippon Pure Water Co. Ltd., Japan*
[e] *Tokyo Institute of Technology, Japan*
[f] *Seavac Corp. Ltd., Japan*
[g] *Graduate School of Frontier Science, University of Tokyo, Japan*
[h] *Centre de Développement des Energies Renouvelables (CDER), Algiers, Algeria*

A R T I C L E I N F O

*Article history:*
Received 12 August 2013
Accepted 18 November 2013
Available online 6 December 2013

*Keywords:*
Energy
Water
SSB
Renewable energy and water
Japan
Sustainability

A B S T R A C T

In this contribution a particular attention is being given to the strategic objective for the establishment of a North Africa (NA) countries cooperation on water and clean energy superhighway as the solution to regional energy challenges, water shortages, climate change and other environmental problems arising from the current fossil-fuel heavy global energy paradigm. Advanced and technical know-how and resources of Japan, through the Sahara Solar Breeder (SSB) project, can facilitate to achieve sustainable development in the region, cooperation to accelerate and expand its research activity with ambitious quantitative targets for solutions between the growing water crisis in NA and energy resources (fossil and renewables energies (RE)). With global energy demand set to rise significantly over the next 15 years, there will be a pressing need for fresh investment in new output capacity across the entire water/energy supply chain. It is still believed and emphasized that Photovoltaic (PV) will be a significant contributor within a portfolio of energy sources in the coming 10–20 years and that SSB is providing science and technology that are poised to play a transformative role in providing clean and sustainable water/energy for the whole world. Japan's energy/water innovative strategy for NA is encouraging since problems cannot be solved by one country alone hence local, regional and global cooperation is crucial.



**Contents**



* Corresponding author. Tel.: +213 41 56 03 29; fax: +213 41 56 03 01.
*E-mail address:* stambouli@ssb-foundation.com (A. Boudghene Stambouli).
*URL:* http://www.ssb-foundation.com/ (A. Boudghene Stambouli).

1364-0321/$ - see front matter 
http://dx.doi.org/10.1016/j.rser.2013.11.042

## 1. Introduction

As we approach a 2050 (10 billion persons on earth), physical and environmental constraints in our use of water and energy resources are beginning to manifest themselves. We also live in a time of uncertainty – in food security, energy and water supply and climate change, for example – and our demands on the environment continue to increase. This new situation calls for the scientific community to take up the challenges to provide a greater understanding of our nature which clearly is in need for a scientific and technological approach to sustainable development and that science and technology must be a driving force in the development of societies. Water and energy resources, intricately connected and increasingly scarce, are integral parts of the heritage of humanity. They require us to implement policies and strategies adapted to sustainable development because:

- Energy security, Economic growth and Environmental protection are the national energy policy drivers of any country of the world;
- Energy is central to achieving the interrelated economic, social, and environmental aims of sustainable human development;
- Water is a fundamental part of our lives. It is a free and renewable natural resource. Human survival is dependent on water which has been ranked by experts as second only to oxygen as essential for life;
- Energy and water resources are intricately connected: we use energy to help us treat, clean and transport the water we need, and we use water to help us produce the energy we need.

According to the estimation done by the International Energy Agency (IEA) [1], a 53% increase in global energy consumption is foreseen by 2030, energy security is becoming a serious issue as fossil fuels are non-RE and will deplete eventually in near future. In addition, the world's oil resources will peak within a few decades to come (80 years at the most), and in the search for other sustainable alternatives to mitigate some political, economic and environmental issues currently associated with the heavy reliance on fossil fuel, it is inevitable that the world is heading towards RE and new energy economy, to reach sustainability, by promoting clean energy technologies, pursuing energy efficiency and developing RE forms which are three orders of magnitude larger than current global energy use [2,3]. Moreover, climate changes, manifested in various forms, threaten the fragile balance of our ecosystem and require us to implement policies and strategies adapted to sustainable development.

2For this reason, NA countries seek technologies from all disciplines applicable in RE, energy efficiency (EE) and water. Indeed, considering them together, by improving access to clean water and green modern energy, offers substantial economic and environmental benefits for the region as well as a unique opportunity of technological advancing in the energy and water fields. The idea of valorisation of water and energy resources for innovation in NA is to give a vision about the future, take into account the experience of the water and energy sectors during the last decade, about the development of the RE, focused from a double perspective: regulative and technological.

While the NA region has shortage in water resources, due to the semi-arid climate and an increasing demand created by population and economic growth, it is blessed with overwhelming distributed RE sources in that solar energy is called to be one of the most relevant players in the basket of the future as seen in Figs. 1 and 2 [4–6]. Energy of sun shine in NA, also known as the Sunbelt, is huge, 0.01% utilisation would cover the entire world.

Although fresh water supplies remain constant in NA, the demand for water increases every day. As the region's population continues to grow, per capita water availability is set to fall by 40% by 2050 with a decrease in water supply by 12% as depicted in Fig. 3 [7,8]. Annual rainfall is likely to decrease in much of Mediterranean Africa and Northern Sahara.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [9] projects strong changes in climate across the MENA region. Temperature increases combined with substantial decreases in precipitation are projected. An increase in temperature results in a higher evapotranspiration demand and will, in combination with a decrease in precipitation, severely stress the water resources in the region. The need for alternative and improved water management options is therefore urgently needed. In addition, the need to develop innovative practices and technologies to maximize the use of what is naturally available is an on-going challenge for NA water experts, policymakers, and the general public.

NA population is young and has one of the world's most rapidly expanding populations. Table 1 neatly summarizes population growth since 1950, and also project growth to 2050, based on United Nations (UN) and International Monetary Fund (IMF) data [10,11]. This offers a unique opportunity of technological advancing in the water/energy field. Indeed, improved access to clean water and green modern energy in the region is a fundamental step to poverty reduction with advanced and technical know-how and resources of the industrialized nations can facilitate to achieve sustainable development in the region.

## 2. Water and energy linkage

Energy, in absolute terms, is not in short supply in the world. Exactly the same can be said about water. The world's total annual use of commercial energy is on the order of 400 Quads [12], and the sun pours about 6 million Quads of radiant energy into the earth's atmosphere each year. In addition, the earth is a water rich planet, and annual human and animal consumption is much less than 1% of the world's total water supply. What is in short supply is cheap energy and cheap potable water that people can afford to buy. Therefore, water and energy are the critical elements of sustainable development and without access to both, economic growth and job




**Fig. 1.** Potentials of solar in NA region (Economic Potential > 600 000 TWh/yr, Maximum yield 250 GWh/km$^2$).

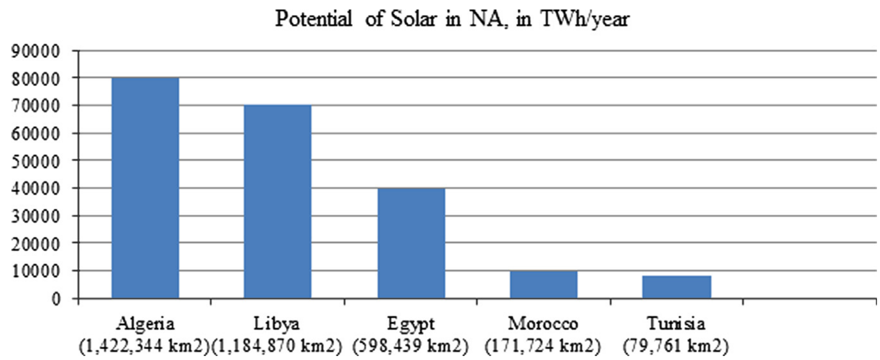



**Fig. 2.** Statistic prediction of the potential of solar electricity generation in NA (TWh/yr).

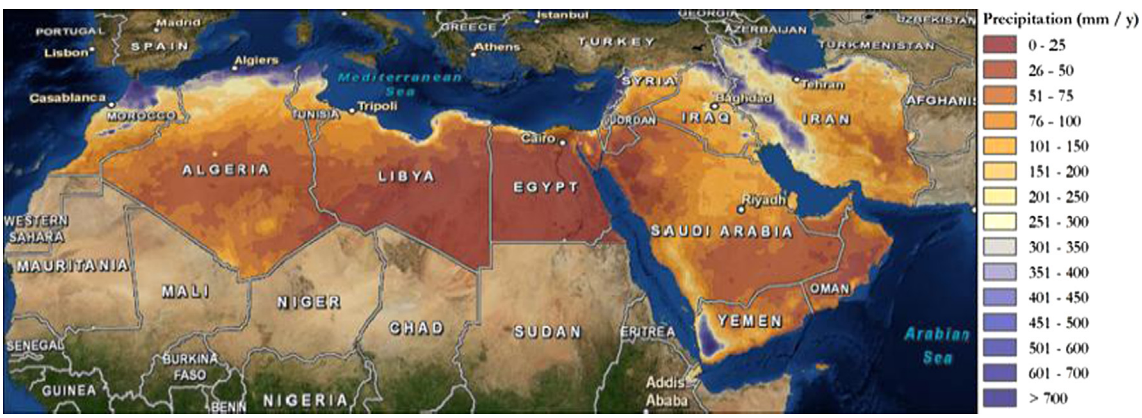



**Fig. 3.** Map of yearly average precipitation in NA region.

**Table 1**
Population size and growth in NA: 1950, 2007 and 2050.

| Country | Population in thousands | | | Ratio of population | |
|---|---|---|---|---|---|
| | 1950 | 2007 | 2050[a] | 1950/2007 | 2007/2050 |
| **Algeria** | 8753 | 33,858 | 49,610 | 3.9 | 1.5 |
| **Egypt** | 21,834 | 75,498 | 121,219 | 3.5 | 1.6 |
| **Morocco** | 8953 | 31,224 | 42,583 | 3.5 | 1.4 |
| **Libya** | 1029 | 6160 | 9683 | 6.0 | 1.6 |
| **Tunisia** | 3530 | 10,327 | 13,178 | 2.9 | 1.3 |
| **Northern Africa** | 44,099 | 157,068 | 236,272 | 3.6 | 1.5 |

[a] Projected.

creation cannot take place and poverty cannot be averted. A myriad connections exist between our demand for and use of energy and water, and suggests that there are strong parallels between the growing water crisis in NA and energy resources (fossil and renewables), as well as between the solutions to both problems. It is important to emphasize again that we can no longer take water resources for granted if NA region is to achieve energy security in the years ahead. This is also true of other regions as well, and reflects the strong linkage between water and energy, as well as a growing water security crisis world-wide.

Water and energy uses are closely linked in that energy production uses and pollutes water and water use requires significant energy (globally, commercial energy consumed for delivering water, such as lifting ground water, desalinating, treating and pumping water through pipes, is about 7% of total world consumption) [13]. Limits to each are beginning to affect the other; yet energy and water issues are rarely integrated in policy. Energy and water policy can also be expressed in similar terms. The first priority of energy policy should be the wise, efficient use of whatever energy supplies are available. The same is true of water – priority should be given to the wise, efficient use of whatever water supplies exist. By considering water and energy together will offer substantial economic and environmental benefits for the NA region. In addition, the realities of climate change affects policies in both areas. It is after focusing on efficient use of existing resources that attention must be focused on new energy and water supplies that meet sustainability and environmental requirements. We therefore need to achieve the following objective:

- Establish strong links with the political process that lead to recommendations which will advise governments on the best approach to the links between water and energy;
- Establish common understanding and cooperation between actors from the water and energy sectors;
- Establish a network of policy makers in charge of water and energy involving developed countries and developing countries of NA to enhance levels of dialogue and awareness on all aspects link water/energy;
- Initiate a major new research program that will address the connection between water/energy availability and economic sustainability.

Issues the society is facing today and that we need to overcome are:

- Climate change (mostly from burning fossil fuel)
- Increase in the prices of limited energy and water resources

- Increase in the prices of energy-intensive commodities like fertilizer
- Air and water pollution
- Economic development in all aspects
- National security
- Poverty and global health
- How to keep society free of geopolitical conflict
- ………………

We have much to contribute all, as a social responsibility duty, to achieve water and energy security, the linkage between the two must be recognized and acted upon. Without access to both, economic growth and job creation cannot take place and poverty cannot be averted. Fig. 4 shows how we need science and technology that are poised to play a transformative role in providing clean and sustainable water and energy. SSB project may be a solution!

### 2.1. *Various forms of energy*

Energy is the engine of the universe, engine of all the fundamental processes of the nature on earth and engine of the world economy. The world is full of energy resources but their supply is finite. It also needs to be converted into power in order to make use of it. Our response is to find ways to use these resources more efficiently and develop new sources for energy. The different forms of energy are summarized as being fossil, fissile, renewable and new energies which can be presented as: Mechanical, Chemical, Electrical, Nuclear and Thermal energies. Energy researchers should creatively apply their knowledge of science (physics, math and chemistry), engineering (electrical and mechanical) and economics to confront the global challenges of energy supply and demand [14] (Fig. 5).

#### 2.1.1. *Energy and sustainability*

To understand the implications for energy supply, Table 2 presents a brief review of the energy linkage with other sustainable development issues such as water, health, biodiversity and agriculture. Energy availability can, therefore, severely constrains the four critical elements of sustainable development, a major goal of NA countries policy.

Population growth and economic development are driving a steadily increasing demand for new energy supplies, and global demand for energy has more than tripled over the past half century. The future demand for electricity, assessed from time to time by the IEA, shows that the world's electricity consumption is expected almost to double by the year 2020 [15].

Table 3 shows clean energy, expressed as a percentage of total energy use in NA's countries. Clean energy is non-carbohydrate energy that does not produce carbon dioxide when generated. It includes hydropower, geothermal, wind and solar power, among others. Note that the Arab world presents a percentage of total energy of about 0.39. Table 3 also shows the values of energy intensity in 2050. Energy intensity is a measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of GDP (high energy intensities indicate a high price or cost of converting energy into GDP and low energy intensity indicates a lower price or cost of converting energy into GDP).

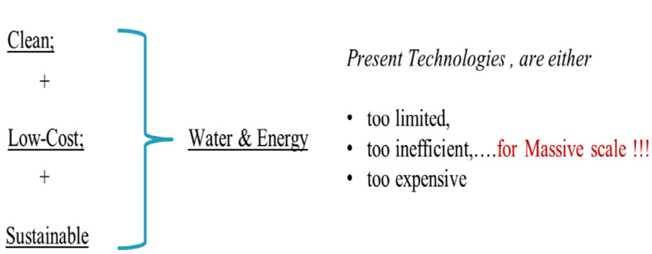



**Fig. 4.** Issues the society is facing today.

### 2.2. *Various forms of water*

An important feature of the earth's supply of fresh water is its non-uniform distribution around the globe. Water, for which there are no substitutes, has always been mankind's most precious

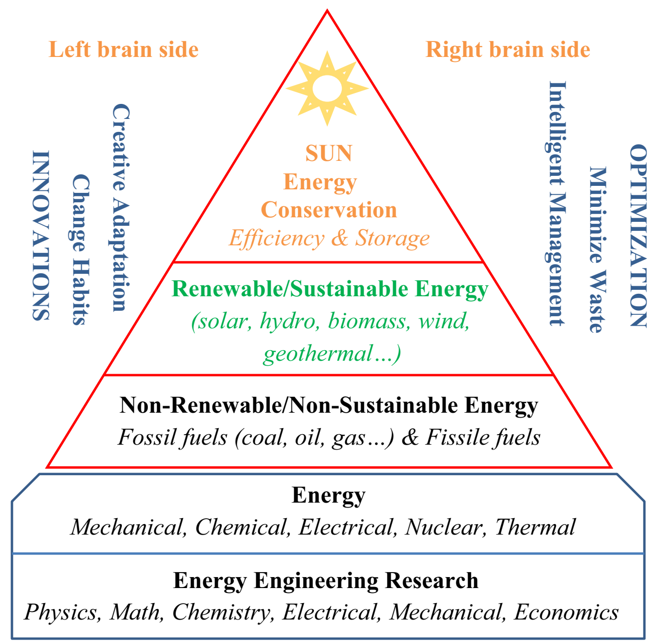



**Fig. 5.** Energy engineering main research areas, forms of energy and energy pyramid.

**Table 2**
Energy supply and use in connection with water, health, biodiversity and agriculture.

| Energy supply and use | |
|---|---|
| **Energy and water** | • *Potential to provide safe drinking water through desalination and treatment*<br>• *Acidification of water bodies*<br>• *Hydropower impacts* |
| **Energy and health** | • *Potential for improving health care facilities*<br>• *Traditional fuel use health impacts*<br>• *Health impacts of air pollution*<br>• *High environmental impact* |
| **Energy and biodiversity** | • *Bio-energy production to revive degraded land*<br>• *Hydropower's impact on species and ecosystems* |
| **Energy and agriculture** | • *Increase productivity through modern energy sources*<br>• *Bio-energy as a new source of fuel* |

**Table 3**
Alternative energy [16] and energy intensity [17] by country in NA.

| Country | Alternative energy (percentage of total energy use) (%) | Energy intensity 2050 |
|---|---|---|
| **Algeria** | 0.1 | 1.87 |
| **Egypt** | 1.9 | 3.19 |
| **Morocco** | 0.71 | 1.11 |
| **Libya** | 0 | No data available |
| **Tunisia** | 0.07 | 1.31 |

resource. The struggle to control water resources has shaped human political and economic history, and water has been a source of tension wherever water resources are shared by neighbouring peoples. Globally, there are 215 international rivers and 300 ground water basins and aquifers shared by two or more countries [18].

There may be renewable and non-renewable sources of water in that:

- Non-renewable resources are stock limited with no effective recharge;
- Renewable resources are flow limited;
- Water and energy exhibit characteristics of both: but while most of our water use is renewable, most energy use is non-renewable.

Renewable water is continuously renewed within reasonable time spans by the hydrological cycle, such as that in streams, reservoirs, or aquifers that refill from precipitation, runoff, or groundwater recharge.

We will never run out of water overall, it is (mostly) renewable. We will run up against renewable flow limits that are a combination of natural and economic constraints. Where water is non-renewable we will run into stock constraints. We are increasingly hitting (or exceeding) peak ecological water limits. Hitting these limits has social, economic, and political implications (Fig. 6) [18].

### 2.2.1. Water and sustainability

The water linkage with some important aspects of lives, such as education, health, poverty and hunger, is depicted in Table 4. The importance of access to clean water cannot be overstated. Poor health, hunger and a lack of education are symptoms of the true problems: No clean water. Together they lead to a cycle of poverty.

The column 1 of Table 5 shows the total renewable water resources in NA's countries. It corresponds to the maximum theoretical yearly amount of water actually available for the country at a given moment. Note that the current world total renewable water resources: ~53,719 $km^3$/year. Total renewable water resources provides the water total available to a country but does not include water resource totals that have been reserved for upstream or downstream countries through international agreements. Note that these values are averages and do not accurately reflect the total available in any given year. Annual available resources can vary greatly due to short-term and long-term climatic and weather variations.

The column 2 of Table 5 shows total renewable water resources per capita by country. Note that the current world total renewable water resources: ~24,776 $m^3$/inhabitant/year (24,776,000 l for each person).

The column 3 of Table 5 shows the per cent of total renewable water resources dependency ratio or originating outside the country. Dependency ratio may theoretically vary between 0% and 100%. A country with a dependency ratio equal to 0% does not

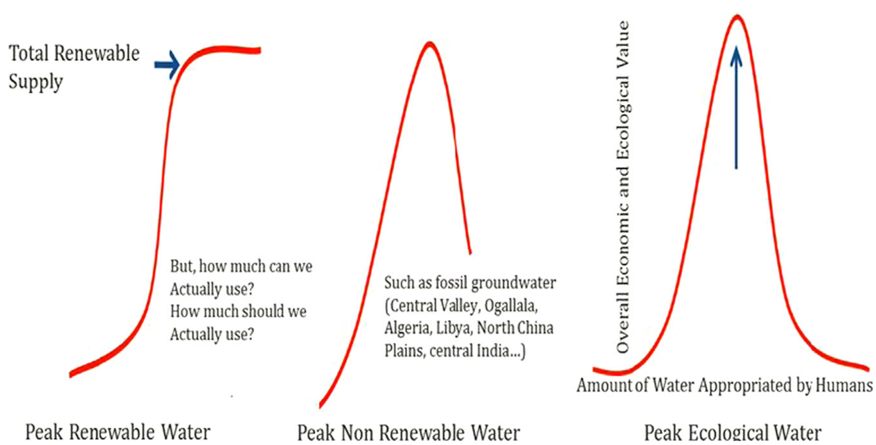



**Fig. 6.** Peaks of renewable, non-renewable and ecological water.

**Table 4**
Water supply and use in connection with education, health, poverty and hunger.

| Water supply and use | |
|---|---|
| Water and education | • Education is critical for breaking the cycle of poverty<br>• Lack of clean water has serious effects on student's academic performance and attendance rates<br>• Lack of clean water = education simply becomes less of a priority = Lack of Equality |
| Water and health | • Potential for improving health care facilities<br>• 1 out of every 5 deaths under the age of 5 worldwide is due to a water-related disease<br>• Good health begins with access to clean water<br>• Poor health leads to poor productivity<br>• Clean and safe water is essential to healthy living |
| Water and poverty | • Poverty begins with a lack of clean water and can be the result of a lack of access to clean drinking water<br>• Nearly 1 in 8 people on the planet do not have access to clean, safe water<br>• Without clean water, the possibility of breaking out of the cycle of poverty is incredibly slim. |
| Water and hunger | • Globally we use 70% of our water sources for agriculture and irrigation, and only 10% on domestic uses. Water scarcity translates to a loss of food security<br>• Water is fundamental to relieving hunger in the developing world. 84% of people, who don't have access to improved water, also live in rural areas, where they live principally through subsistence agriculture. |

receive any water from neighbouring countries. A country with a dependency ratio equal to 100% receives all its renewable water from upstream countries, without producing any of its own. This indicator does not consider the possible allocation of water to downstream countries.

The column 4 of Table 5 shows surface water and ground water withdrawal as percentage of total renewable water resources. Water withdrawal is the quantity of water removed from available sources for human use (in the agricultural, domestic and industrial sectors), expressed as a percentage of the total volume of water available annually through the hydrological cycle (total actual renewable water resources). The terms water resources and water withdrawal are understood as freshwater resources and freshwater withdrawal.

[Freshwater withdrawal as % of total renewable water resources (actual)] = 100*[Total freshwater withdrawal (surface water + groundwater)]/[Water resources: total renewable (actual)]

The column 5 of Table 5 shows total water withdrawal per capita by country. Water withdrawal is the quantity of water removed from available sources for use in any purpose. Water drawn-off is not necessarily entirely consumed and some portion may be returned for further use downstream.

#### 2.2.2. Water stress and security risk indexes

NA region is rated as having the least secure water supplies in the world. The five key components of water security, for the NA countries, are given below in Tables 6 and 7 [21].

Indexes include: access to improved drinking water and sanitation; the availability of renewable water and the reliance on external supplies; the relationship between available water and supply demands and the water dependency of each country's economy.

The use of water varies greatly from country to country in NA region. Data on water use by countries and by different economic sectors are among the most sought after in the water resources area. The quantities of freshwater withdrawal by country and by domestic, industrial and agricultural sectors in NA are shown in Tables 8 and 9 [22,23]. We all hope to seek inspiring ideas for future water development and explore ways for sustainable development. This is highly important for preserving our common homeland, the Earth, and promoting its prosperity by acting as a catalyst in the development of NA region.

## 3. Energy research themes for NA

In their plans to move beyond heavy dependence on fossil fuel imports (Morocco and Tunisia) or to maximize export revenues from domestic oil and gas reserves (Libya, Algeria and Egypt), the NA countries stand at a crossroads in terms of energy policy: interest in adopting RE and/or nuclear energy presents opportunities for a strategic realignment of national development paths. Placed in the global Sunbelt, rich in wind, geothermal and hydropower resources, the NA countries boast abundant potential for RE production. Although a series of clean energy policy initiatives have recently been introduced in the region, RE resources largely remain untapped. Current efforts to establish large-scale solar power exports to the European Union (EU) – including the Mediterranean Solar Plan, the Desertec and the SSB project – anticipate a substantial uptake of RE in NA [24]. In this section, we try to provide a platform to analyse recent trends in the NA energy systems research, as well as their implications for wider energy governance, in the context of this current crossroads for strategic energy investment and development.

### 3.1. Energy training and technology transfer, main categories

Current trends and prospects for RE in NA, covering optimization of market and technological options, regional energy infrastructure challenges (e.g. in terms of generation capacity, energy security and integration with European energy and carbon markets) and political-economic governance contexts are analysed. There are also in-depth insights on clean energy policy development in NA. Training and technology transfer, main categories, on energy, can be summarized as follows:

- Technologies that are currently applicable for world-wide cost-effective application (energy efficient buildings, off-grid PV, commercial solar water heating);
- Technologies in need of minor development (CSP stations, wind energy);
- Energy science-based approach towards developing smart solutions;

**Table 5**
Total renewable water resources by country in NA [19,20].

| Country | Renewable water resources ($km^3$/yr) | Renewable water resources per capita ($m^3$/yr) | Renewable water resources dependency ratio (%) | Proportion of total water resources used (%) | Total water use per capita ($m^3$/yr) |
|---|---|---|---|---|---|
| **Algeria** | 11.67 | 339.5 | 3.6 | 52.65 | 196 |
| **Egypt** | 57.3 | 702.8 | 96.86 | 119 | 937 |
| **Morocco** | 29 | 917.5 | 0 | 43.41 | 427.2 |
| **Libya** | 0.6 | 95.33 | 0 | 718 | 776.8 |
| **Tunisia** | 4.6 | 451.9 | 8.71 | 61.74 | 296.2 |

**Table 7**
Secure water supplies in NA.

| North Africa country | Water stress category | Water stress index | Water use as % of renewable resource | Water security risk index |
|---|---|---|---|---|
| **Morocco** | Extreme | 12 | 43.41 | 16 |
| **Algeria** | Extreme | 13 | 52.65 | 18 |
| **Tunisia** | Extreme | 15 | 61.74 | 17 |
| **Libya** | Extreme | 5 | 71.8 | 14 |
| **Egypt** | Extreme | 9 | 11.9 | 4 |

**Table 6**
Key components of water security.

| Overall water security = $A+B+C+D+E$ | |
|---|---|
| Component | Definition |
| $A$ = Basic household needs | The percentage of population with sustainable access to an improved water source |
| $B$ = Agriculture production | The extent to which water is available and harnessed for agriculture production |
| $C$ = Environment flows | Percentage of renewable water resources available in excess of environmental water requirement |
| $D$ = Risk management | The extent to which countries are buffered from effects of rainfall variability through large dam storage |
| $E$ = Independance | The extent to which countries water and food supplies are safe and secure from external changes or shocks |

**Table 8**
Annual freshwater withdrawal by sector in NA.

| North Africa country | Year | Total freshwater withdrawal ($km^3$/yr) | Per capita withdrawal ($m^3$/p/yr) | Domestic use (%) | Industrial use (%) | Agricultural use (%) |
|---|---|---|---|---|---|---|
| **Morocco** | 2000 | 12.6 | 389 | 10 | 3 | 87 |
| **Algeria** | 2000 | 6.07 | 171 | 22 | 13 | 65 |
| **Tunisia** | 2000 | 2.64 | 254 | 14 | 4 | 82 |
| **Libya** | 2000 | 4.27 | 652 | 14 | 3 | 83 |
| **Egypt** | 2000 | 68.3 | 809 | 8 | 6 | 86 |

**Table 9**
Annual quantity of freshwater use by sector and by person in NA.

| North Africa country | Population in 2010 (Millions) | Domestic use ($m^3$/p/yr) | Industrial use ($m^3$/p/yr) | Agricultural use ($m^3$/p/yr) |
|---|---|---|---|---|
| **Morocco** | 32.38 | 39 | 12 | 339 |
| **Algeria** | 35.42 | 38 | 23 | 111 |
| **Tunisia** | 10.37 | 36 | 10 | 209 |
| **Libya** | 6.55 | 91 | 20 | 541 |
| **Egypt** | 84.47 | 62 | 49 | 695 |

- Appropriate strategies to provide training for the optimization and management of energy use that contributes to a prosperous environment (climate-friendly energy supply);
- Provide NA partners with access to the, for example, Japan's Universities advanced energy and sustainability research topics. The two sides communicate their research information and findings for procession and dissemination in the framework of the SSB project for example;
- As for EE, technologies are sought that can be deployed within NA's operations or more broadly in the MENA region to reduce energy consumption, carbon emissions, and reduce the rapid growth in domestic demand (air conditioning and cooling during summertime). There are many other opportunities for efficiency improvements including building and construction materials, waste heat recovery systems, lighting, etc.
- Sharing best practice examples to relevant energy sector (share projects aiming at improving social and community services, at management of natural resources and at creating income-generating activities);
- Unlocking climate finance: evaluating the current financial situation to determine how much more is required to reach current RE generation targets;
- Find how can solar energy act as a creator of sustainable jobs in NA?

### 3.2. *Energy innovative research for NA*

In this section, we briefly set out some proposed innovative researches areas for the interest of NA countries in alternative energy futures. These are proposed below:

- In sunny NA, solar energy is the energy source of today and tomorrow. And, from the west to the east of the region, wind energy can be used. Both alternative energy sources will play a key role in the SSB and Desertec projects;
- New technologies with a view to long term energy sustainability;
- NA has lots of open land, and lots of sand which is rich in silicon; which is needed to make poly-silicon for the solar industry (joint venture with the Sahara Solar Breeder project team). With this move, NA, with the help of Japan, can slowly begin to make some moves diversifying out of oil, which is its only real exportable commodity – and towards solar power and sand-based poly-silicon, the commodities that it is truly rich in. And since NA is expected to be among the major PV growth regions during next years, it will be considered as a smart move;
- Establish a conceptual and analytical framework for the assessment and monitoring of energy impacts on the environment;
- Since NA has abundant solar energy resources suitable for both concentrating and non-concentrating systems. We seek innovative research in solar technologies; particularly those tackling unique challenges to solar systems in the region such as extreme ambient temperatures, dust, sand, humidity…;
- Identifying research challenges and trends in solar power generation;
- NA seeks to be involved in the breakthrough technologies which are applicable in NA's operations, or more generally of strategic importance to the region.

The International Renewable Energy Agency (IRENA) and the Renewable Energy Policy Network for the 21st Century (REN21) recently published a joint report examining the deployment of RE in the NA region. This latter, the report says, is currently characterized by an increasing amount of renewable power investment and a burgeoning project pipeline to harness the region's abundance of renewable energy resources. The report also finds that PV is experiencing rapid growth due to its tremendous potential and continuously decreasing technology costs, with a current pipeline of almost 2 GW [25]. Note that from 2008 to 2011, the average annual growth rate of solar PV production was at least 112% [25]. NA countries with solar PV projects in the pipeline include Algeria (175 MW), Egypt (106 MW), Morocco (127.7 MW) and Tunisia (5 MW).

## 4. Water research themes for NA

Countries in NA region face problems of water shortage due to the semi-arid climate and an increasing demand created by population and economic growth. The water situation in NA region is precarious. Population and development have overwhelmed traditional management practice. It is projected that the per capita renewable water supply will fall from 3430 $m^3$ in 1960, to 667 $m^3$ in 2025. In several countries of the region, renewable freshwater will barely cover basic human needs within two decades. Development of water resources has been impeded by various reasons including the lack of technology and public awareness.

With the political movement in NA under way (Tunisia, Libya and Egypt), water issues have to take the centre stage. Co-operative water resources development should immediately follow to maintain a sustainable growth and prosperity. In view of the impending needs, a regional water resources consortium should be formed to provide training and technical assistance, to promote information and technology exchange, to provide expertise for arbitrating water conflicts (if happened), to organize long term and regional planning, and to serve as a centre of excellence for relevant technologies in the region using information

technology support [26,27]. Managing water resources and preserving water quality require regional and international efforts.

### 4.1. Water training and technology transfer, main categories

Technology provides opportunities for helping resolve some of these problems. Information on existing technology and science can be a basis for creating co-operative actions amongst countries in the region. Training and technology transfer, main categories, on water, can be summarized as follows:

- The availability of potable water is one of the most pressing issues in the world, particularly in the MENA region where water production is a costly and energy-intensive process. With the NA's growing economy and rising population, it is crucial to identify a sustainable desalination solution to meet the long-term water needs;
- NA countries should launch renewably powered desalination projects, existing desalination technology will of course continue to play its role in providing safe water. The water concerned research will have to explore ways to harness natural resources, like solar and wind. The overall goal is to have a utility scale desalination plants that will be powered by either solar, wind or even a combination of the two or several other technologies if necessary;
- Connecting desalination technologies to renewable energy enables the NA countries to capitalize on their abundant resources, such as solar, as a solution to improve water security. New, less energy-intensive water cleansing techniques could revolutionize NA's desalination industry, free up important energy exports and provide residents a greater sense of water security;
- Research in technologies applicable across the water value chain including, distribution, end-use, water and wastewater treatment, and recycling;
- Develop appropriate strategies and provide training, design documents and counselling services for the proper optimization and an integrated management of water use that contributes to a prosperous environment.

### 4.2. Water innovative research for NA

The objectives of innovative research for NA are to initiate a scientific body aiming to organize efforts on water resources, quality, and economic issues in the region. This will also serve as a consulting arm for governments in the region initiating national or international water conservation, environmental protection, management, and utilisation projects. The need to develop innovative practices and technologies to maximize the use of what is naturally available is an on-going challenge for NA water experts, policymakers, and the general public. Innovative researches on water in NA are proposed below:

- Getting to grips with the threats to water security is not straightforward and requires innovative and dedicated approaches. Possible responses include increasing supply, managing demand and allocating water differently;
- Seek new technologies in the areas of ground and surface water, water recycling dams, reservoirs, channels, water standards, agriculture and irrigation, coastal and port engineering, and health expertise;
- Find proper technology implementation and orientation suitable for NA;
- Development of a Water Information System Mapping for the collection of available scientific data on water resources and provide economic assessment of water supply projects and programs;
- Implementation of integrated approach to water resources management;
- Research on the environmental issues in water management and incorporation of environmental concerns into decision-making;
- Needs joint venture research for water engineering perspective, water education and public water quality awareness;
- Sharing of information is a first step toward international co-operation. A regional water network can not only serve as a repository for valuable water data and an access for computer software, but also provide a posting place for newest technology, a forum for exchange information and expertise advise;
- Build an on-line information resources system to help enhance and improve communication and information sharing amongst water resources professionals in the region;
- Find new and innovative solutions to water scarcities that do not sop up the country's own energy.

## 5. Sahara solar breeder, a new global climate policy

The SSB plan involves building manufacturing plants around the Sahara desert that would extract silica from the sand and turn it into solar panels to generate renewable energy. The renewable energy from the first facility will then be used to breed more manufacturing plants and, in turn, more solar panels to generate ever increasing amounts of solar power. The ultimate goal is to build enough plants until the breeding strategy can deliver 100 GW of electricity to provide 50% of the world's electrical power generation capacity by 2050 which would be delivered via a global superconducting electrical grid to turn the world's biggest desert into the world's biggest power station taking advantage of two resources that are found in abundance in the Sahara namely silica and sunlight (Fig. 7) [28].

Embracing NA region's considerable potential as the world's renewable energy powerhouse. The development and realization of the SSB project, in the Sahara of Algeria which covers a total area of 2,048,297 km2, approximately 86% of the total area of the country, will tackle the key challenges and issues related to the field of PV putting forward the material R/D perspective and promoting innovative processes for solar silicon with a focus on the utilisation of Sahara sands. Three Ss should be the national energy policy drivers of Algeria namely: Solar, Sand and Space [29]. SSB is a project which proposes a plan of international partnership in basic research and development, industrial production, trade, financing… to construct, gradually over the coming decades, a “Global Clean Energy Superhighway” starting in the Sahara desert in NA (beginning from Algeria) (Fig. 8) [30].

SSB will help migrate from the unsustainable current excessively fossil-fuel-based global energy paradigm to a more sustainable one. It will also help meet global energy challenges, and mitigate climate change and other environmental problems. SSB is more than an energy solution. It is an integrated community, socio-economic, industrial, agricultural, environmental, and science and technology development solution. In particular, through desalination and adequate irrigation technologies, it will help mainstream marginal desert water resources and lands back into national, regional and international development processes. The concept of the SSB is depicted in Fig. 9 [29–31]. Scenarios help us understand the limitations of our ‘mental maps’ of the world – to think the unthinkable, anticipate the unknowable and utilise both to make better strategic decisions.

SSB has a clever global development strategy for solving the energy, water and climate problems with existing solar grade Silicon production from Sahara sand technology for a world in a sustainable way. The SSB project serves as the initiative for the super Apollo project [32] to provide the paradigm shift in the

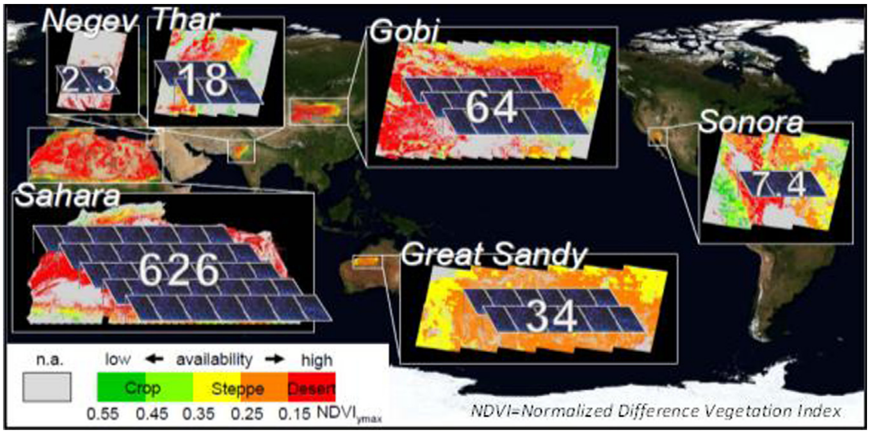



**Fig. 7.** Solar resources of the world six deserts (TW).

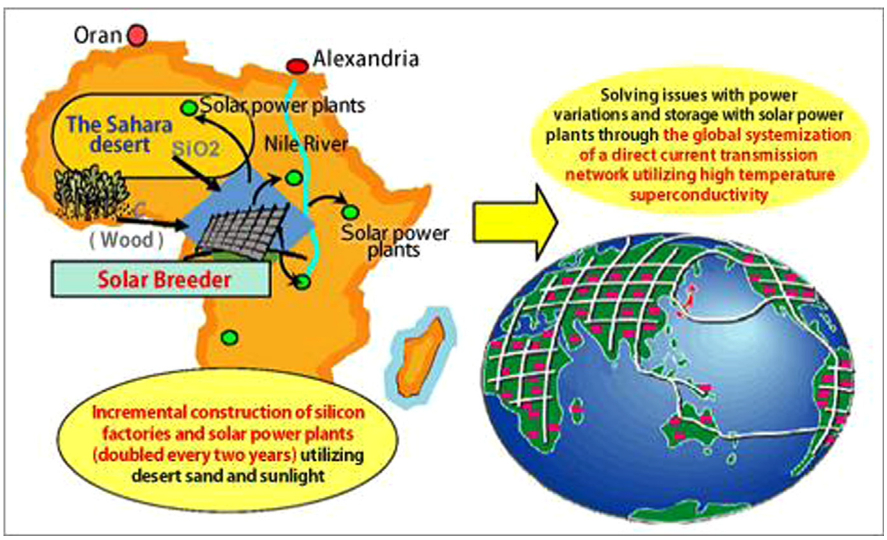



**Fig. 8.** SSB concept and plan.

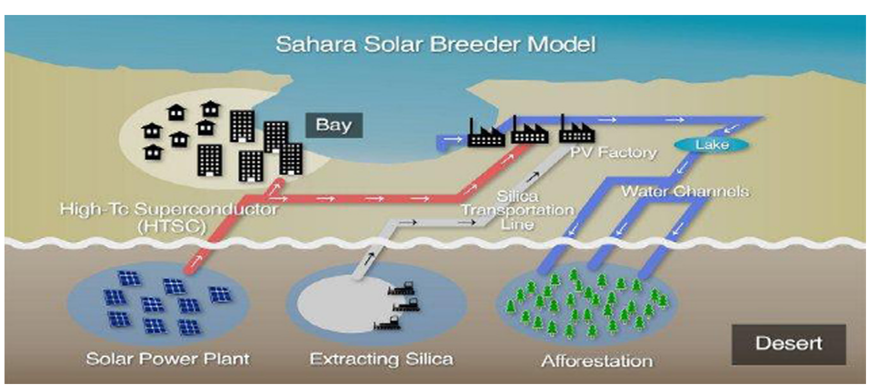



**Fig. 9.** SSB model, key to a sustainable civilization.

global energy system. SSB merits and difference from other projects is that:

- High skill jobs are created continuously.
  - People enjoy to study and work over generations.
- Deserts are converted to area for more life.
  - Happy to manage growth of own economy.
- Sustainable distribution of energy to the globe.
  - Supporting the world sustainability (social responsibility).

## 6. Energy/water research needs and priorities in NA

The idea of valorisation of water and energy resources for innovation in NA is to give a vision about the future, take into account the experience of the water and energy sectors during the last decade, about the development of the renewable energies, focused from a double perspective: regulative and technological (solar energy is called to be one of the most relevant players in the renewable energy basket of the future). The proposed energy and

water research needs and priorities in NA can be identified as follows:

- Making the region more energy-efficient;
- Peak water limits;
- Unavailability of water;
- Needs for water engineering and water education (Almost all renewable energy applications need running water);
- Quantify peak of non-renewable and ecological requirements limits, e.g., measuring groundwater use and recharge;
- Assessment and monitoring of energy impacts on water;
- Assess the direct and indirect impacts of climate change;
- The reality of climate change affects policies in both areas;
- The risks of water related disputes are growing, including over "peak water" constraints of all kinds!!!
- Methodology analysis and Management of international environmental conflicts on rivers (Nile).
- Bridge the gap between research centres and industry;
- The urgent need for unified policies and regulations within the North Africa region;
- Public energy awareness;
- Writing research proposals and formulating research objectives are important;
- Make planning for long term national projects;
- Encourage the creation of national research funding agencies;
- Market penetration of RE and water related issues;
- Cooperation between local and foreign experts;
- Seek to invest in technologies applicable across the water value chain, including desalination, distribution, end-use, water and wastewater treatment, and recycling.

A March 2013 report by World Bank's Independent Evaluation (IEG) Group [33] found that the effects of water shortages are felt strongly by 700 Million people in 43 countries, including NA countries. We are, therefore, facing daunting challenges. Worldwide scientists suggest that by 2030 the world will need to produce 50% more food and energy, together with using 30% more fresh water, while mitigating the causes of, and adapting to climate change [34]. Effective technical solutions to be adopted or applied and that can aid us in confronting and resolving the issues surrounding global Energy/water security already exist. What is needed is the implementation of effective governance, financing and regulation, to allow this technical solutions to take effect. Moreover scientists must engage with policy makers, economists, financiers, energy and water companies, farmers, industry and development agencies in order to build the public–political consensus needed to approach the problem of global energy/water security. A study on managing the water cycle and providing water for agriculture from municipal waste water has been undertaken by Yokoyama of Nippon pure water company [35]. Agriculture accounts for 70% of all water use (and in some countries over 90%) [36]; therefore improved management of resources in this area is vital for any effort to improve not only NA but global water security. In his study, Yokoyama has considered using water that has been used once but can be used again for another purpose, such as agriculture. Fresh water of drinking water quality level can be economically produced from the municipal waste water, which has been discharged as drain, with advanced Reverse Osmosis (RO, pore size of membrane: less than 1 nm) membrane technology. This can also be a significant and a very much attractive new water resource for agriculture in arid area. The new agriculture method in arid area is proposed as follows:

- PV generator is applied for energy resource;
- Fresh water from municipal waste water with RO membrane technology is applied for agricultural water;
- Plant factory of water saving agriculture is applied for cultivation method.
  Water consumption of sunlight type plant factory is 1/2 to 1/10 comparing to the dry-field cultivation method. Water consumption of artificial light type plant factory with light Emitting Diodes (LED) is 1/10 to 1/100 comparing to the dry-field cultivation method [37,38].

Fig. 10 shows a conceptual picture of fresh water production from municipal waste water with RO membrane technology and its application for plant factories with PV generator.

The water treatment system is based on the following steps:

1. A raw municipal waste water is fed to MBR tank directly;
2. The municipal waste water is filtered with MF system which is submerged in MBR tank;

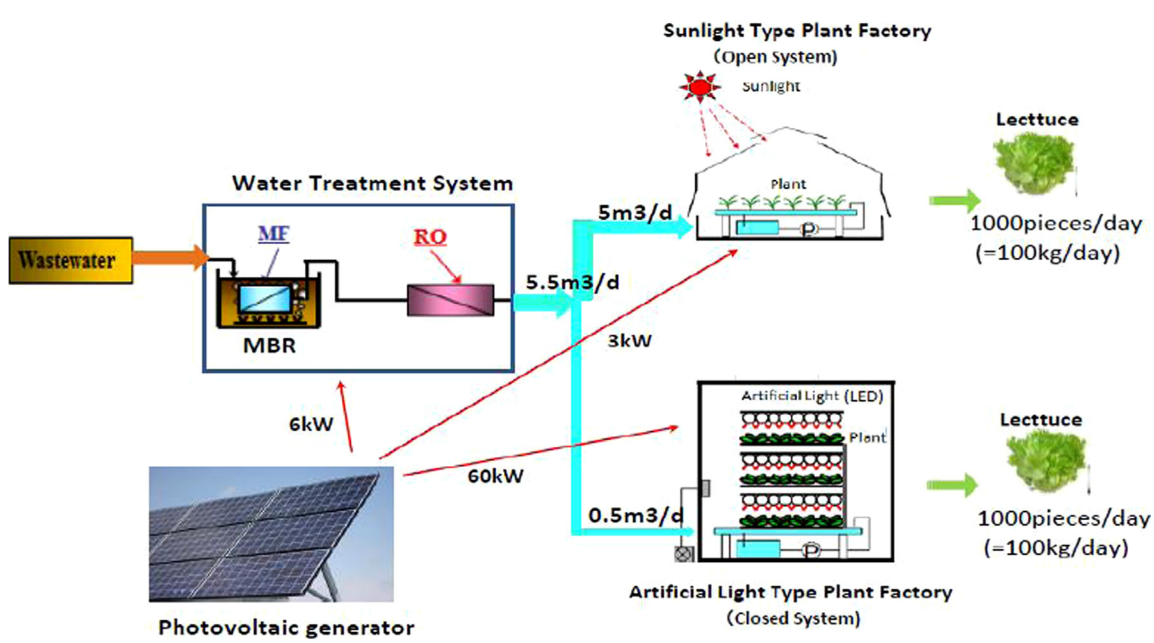



**Fig. 10.** Fresh water production from municipal waste water with RO membrane technology and its application for plant factories with PV generator. MBR: Membrane Bioreactor, MF: Micro Filtration (pore size of membrane: more than 100 nm).

3. As MF membrane removes all suspended materials, the filtrate from MF system is clear but MF membrane cannot remove any dissolved materials of ions and organic materials;
4. The filtrate from MF membrane is fed to RO system, in that RO membrane removes almost all dissolved materials of ions and organic materials, the quality of the RO permeate clears easily the drinking water quality standard.

## 7. Conclusions and recommendations

The importance of access to clean water and energy cannot be overstated. Research, Development and Demonstration (RD&D) are the foundation for progress and change toward sustainable water and energy systems in NA region, protect the global life-supporting systems and reduce the risk of geopolitical conflicts over water and fossil fuel resources which are quickly depleting materials. We need more electricity from Renewables, more investment and initiative to make solar energy cost-effective and competitive (Sahara Solar Project, Desertec) [29]. New, less energy-intensive water cleansing techniques could revolutionize NA's desalination industry, free up important energy exports and provide residents a greater sense of water and energy security. There are good examples of business initiatives to enhance water and energy security for communities in water and energy stressed regions and the lessons of good practice, from experienced countries, need to be more widely disseminated. Cooperation is crucial; problems cannot be solved by one country alone. We need to learn from each other- local, global, regional, cooperation is therefore crucial. Drivers of regional cooperation on water and energy:

- Geography
- Resources endowment/variability
- Trade
- Democracy & Governance
- Power asymmetries
- Diplomatic relationship
- Political regimes
- Colonial heritages!!!

## References


[1] International Energy Agency report 2012. ⟨http://www.iea.org⟩.
[2] Boudghene Stambouli A, Khiat Z, Flazi S, Kitamura Y. A review on the renewable energy development in Algeria: current perspective, energy scenario and sustainability issues. Renew Sustain Energy Rev 2012;16:4445–60.
[3] Boudghene Stambouli A., Survey report on "Renewable Energy Manufacturing Facilities in Algeria" United Nations. Index 2007; 3:382958.
[4] Characterization of solar electricity import corridors from MENA to Europe. DLR: German Aerospace Centre; Stuttgart 2009.
[5] Boudghene Stambouli A. Algerian renewable energy assessment: the challenge of sustainability. Energy Policy 2011;39:4507–19.
[6] Potential of solar in Middle East and North Africa. Energy Tagesfragen, 2013. ⟨http://www.statista.com⟩.
[7] The Middle East and North Africa Regional Water Outlook. World Bank and Utrecht University, LEI (Wageningen) report, 2010–2011. ⟨www.futurewater.nl/uk/projects/mena/⟩.
[8] Terink W, Immerzeel WW, Droogers P. Climate change projections of precipitation and reference evapotranspiration for the Middle East and Northern Africa until 2050. Int J Climatol 2013. http://dx.doi.org/10.1002/joc.3650.
[9] The Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. ⟨www.ipcc.ch/pdf/assessment-report/⟩.
[10] UN Population Division, World population prospects: The 2006 Revision (2007; ⟨http://esa.un.org⟩, accessed April 7, 2007).
[11] International Monetary Fund, Middle East and North Africa: Historic Transitions under Strain regional economic outlook update, April 2012. ⟨http://www.imf.org/⟩.
[12] Hoffman Allan R. The connection: water supply and energy reserves. U.S. Department of Energy (DOE); 2012. ⟨www.energy.gov⟩.
[13] Droogers P, Immerzeel WW, Terink W, Hoogeveen J, Bierkens MFP, van Beek LPH, et al. Water resources trends in Middle East and North Africa towards 2050. Hydrol Earth Syst Sci 2012;16:3101–14, http://dx.doi.org/10.5194/hess-16-3101-2012.
[14] Energy Engineering. Provides resources, strategies, and information on conducting research in Energy Engineering. University of Michigan Library; 2013. ⟨http://guides.lib.umich.edu/content.php?pid=31184⟩.
[15] International Energy Agency report 2010. ⟨http://www.iea.org⟩.
[16] Alternative and nuclear energy (% of total energy use), International Energy Agency, World Development Indicators, The world Bank, viewed 16th November, 2011, ⟨http://data.worldbank.org/data-catalog/world-development-indicators⟩.
[17] Foure J, Benassy-Quereand A.Fontagne L. , Energy Intensity 2050, "the world economy in 2050: a tentative picture", CEPII Working paper 2010-27, viewed 21st November, 2011.
[18] Gleick PH., Peak water and peak energy: implications for security. Water security, risk & society, international water security conference 16–18 April 2012. University of Oxford, UK.
[19] The Food and Agriculture Organization of the United Nations (FAO), AQUASTAT online database, Total renewable water resources. Viewed 15th May, 2011, ⟨http://www.fao.org/nr/water/aquastat/main/index.stm⟩.
[20] ChartsBin statistics collector team 2011, Total renewable water resources per capita by country, ⟨ChartsBin.com⟩, viewed 18th July, 2013, ⟨http://chartsbin.com/view/1470⟩.
[21] Water Stress Index 2011 by Maplecroft news. ⟨http://maplecroft.com/⟩.
[22] Gleick PH, Lucy A. The world's water, Vol. 7. Island Press; 2011–2012.
[23] Sustainable development in cities by SIEMENS, 2013. ⟨http://www.siemens.co.za/sustainable-development/sustainable-development.html⟩.
[24] Mason M, Kumetat D. At the crossroads: energy futures for North Africa. Energy Policy 2011;39(8)(ISSN:03014215).
[25] Tsagas I., Report signals PV boom in the Middle East and North Africa, PV magazine, August 2013. ⟨www.pv-magazine.com⟩.
[26] Ouazar D., Middle East and North Africa Water Resources Consortium and Technology Exchange Network. EMI, MENA Secrétariat Rabat, Morocco. ⟨www.ercim.eu/medconf/papers/ouazar.html⟩.
[27] Middle East and North Africa Water Center Network (MENA WCN): Assessment and Design. November 2010. Publication produced for review by the United States Agency for International Development. ⟨http://mena-nwc.net.s79942.gridserver.com/⟩.
[28] Kurokawa K, Keiichi K, Masakazu I, Peter Van Der V, David F, editors. Energy from the desert- III: IEA-PVPS task-8 report; 2009.
[29] Boudghene Stambouli A, Koinuma H. A primary study on a long-term vision and strategy for the realisation and the development of the Sahara Solar Breeder project in Algeria. Renew Sustain Energy Rev 2012;16:591–8.
[30] Sahara Solar Breeder Foundation website: ⟨http://www.ssb-foundation.com⟩.
[31] Koinuma H, Kurokawa K, Kitazawa K, Fujioka H, Sumiya M, Furuya Y, et al., Oxide initiative to make the dream of 'Sahara Solar Breeder Plan' come true, in: Seventeenth international workshop on oxide electronics, WOE-17 Abst. 100530. Awajishima, Japan.
[32] Koinuma H and Boudghene Stambouli A., Current status and future plan of SATREPS-SSERC (Sahara Solar Energy Research Center) project. 3rd AASEF (3rd Asia-Arab Sustainable Energy Forum) Jointly with 5th International SSB Workshop, Hirosaki, Aomori, Japan, May 6–8/2013).
[33] World Bank's Independent Evaluation Group (IEG), 6th Evaluation Week March 18–21, 2013. ⟨http://ieg.worldbankgroup.org/⟩.
[34] Global Water Security – an engineering perspective. ISBN:1-903496-55-1, April 2010. Published by The Royal Academy of Engineering, London, England. ⟨www.raeng.org.uk/gws⟩.
[35] Yokoyama F., Fresh water production for municipal waste water with membrane technology and its application for plant factory with photovoltaic generation, 3rd AASEF (3rd Asia-Arab Sustainable Energy Forum) jointly with 5th International SSB Workshop, Hirosaki, Aomori, May 6–8/2013. Japan.
[36] Water in a changing world, United Nations World Water Development Report 3, UNESCO, 2009.
[37] Goto E.,The application of green energy in the greenhouse industry in Japan, 2nd International symposium of asian productivity development, Taipai, Taiwan, August 8/2012.
[38] Kozai T. Plant factory with artificial light. Ohmsha 2012 (Japan).